Analysis of Aqua MODIS Prelaunch Polarization Measurements

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Contents

1 Abstract

This report describes the initial problems encountered when analyzing the Aqua polarization measurements done by SBRS. The major issues are the non-repeatability of the measured values for the polarization filter turned by 180°, detector to detector variability, and absence of the expected two-cycle structure for most bands/detectors. This report also describes a likely scenario how the polarization correction for the oceans L2 products was derived by Miami.

2 Introduction

The Aqua polarization was measured by SBRS. A linear polarization filter was turned by 360 degrees in 15 deg increments. MODIS viewed the filter at 5 different viewing angles $(-45°, -22.5°, 0°, 22.5°, 45°)$. Up to 3 runs with different settings were made by SBRS, it is not always clear what is the difference between the settings (one example for different settings: some runs were made with charge subtract off, some with charge subtract=90), but the results from the different runs do not vary significantly, see below.

MCST has provided the filtered raw data, i.e. 101 frames around the polarized signal and 50 frames of the space view for dark current determination. A copy of the SBRS logbook of the measurements is also available, which is necessary to associate the correct rotation angles with the filenames. Unfortunately, some critical information is missing. **With the present knowledge, it is not possible to determine 1) which direction of the polarizer produces horizontally and which direction produces vertically polarized light and 2) if increasing angles of the polarizer correspond to a clockwise or counterclockwise rotation of the polarizer. These two issues must be solved before deriving the MODIS polarization matrix (Mueller matrix) from the prelaunch measurements.** Sam Xiong at MCST did the analysis at MCST two years ago and has been very willing to answer questions, but this information needs to be obtained from SBRS, a task still open.

The Terra polarization analysis has been done by an analyst at MCST who is no longer with MCST. Gerhard Meister asked if we could also get the Terra raw data, but Junqiang Sun (MCST RSB calibration head) was very reluctant to commit to anything specific, since the data is on a tape and does not seem to be in an easily accessible format.

3 Footprint of the polarized signal

The image of the polarizer covers the 10 detectors of the MODIS ocean bands and is about 10 frames wide at the center detectors, about 5 frames for the outer detectors. The image moves by up to 1 or 2 pixels up and down for different rotation angles of the polarization filter. MCST has accounted for this by only using those 3 consecutive frames with the maximum values. This algorithm has been applied in this report as well and will be referred to as 'detector specific'. In the appendix, the plots labeled with the detector number show the polarization signal derived with the detector specific algorithm.

A possible problem is that the image may be moving left/right as well, which means that the optimum signal might be at e.g. detector 2 for one rotation angle of the polarizer and at detector 5 for another angle of the polarizer. If this is the case, the detectors need to be calibrated relative to each other. The prelaunch m1 coefficients from the V4.3.1 LUT were used to calibrate the raw data. The maximum value for 3 consecutive frames for each detector was determined (as in the detector specific algorithm), and the detector with the maximum value was chosen to give the optimum signal.

This was done for each rotation of the polarizer and for each band separately. This technique will be referred to as 'band optimized'.

A look at the detector specific signals for band 8 (Fig. 8, page 15) shows a strong variation of the signal for the different detectors. This is surprising, since it is believed that the polarization sensitivity is mainly produced by other optical components of MODIS, especially mirrors and filters. This suggests that a band specific polarization correction (either the one suggested above or any other) will give better results than a detector specific correction.

The plots in the appendix labeled 'band optimized' show the results derived with the band optimized algorithm in comparison to the detector specific algorithm. The band optimized algorithm produces a pattern that looks closer to the expected two cycle pattern (see below) than the average of the detector specific results, but in each band it may be possible to find a detector that has a pattern that looks closer to the expected 2-cycle pattern than the band optimized algorithm. It has not yet been investigated whether the band-optimized algorithm produces a better pattern than the best detector with the detector specific algorithm, but since it provides a better pattern on average, and since it is quite likely that the image is shifting left/right (because it is definitely moving up and down), it seems to be the best choice for now. (A possible improvement may be to choose that detector as representative for the band whose residuals with a fitted function of the type of eq. 1 are smallest). The band optimized results are shown in Figs. 1 to 5 for viewing angles $-45°, -22.5°, 0°, +22.5°$ and $+45°$.

4 Discussion of measurement artifacts

The expected result of the polarization measurements is a signal with two cycles over the range of rotation angles α of the polarizer from $-180°$ to $+180°$. The expected values $v_e(\alpha)$ can be described by

$$v_e(\alpha) = a_0 + a_2 \cdot \cos 2\alpha + b_2 \cdot \sin 2\alpha \tag{1}$$

The coefficients a_0, a_2, b_2 were retrieved through Fourier transformation of the measured values. This was suggested in [4] as a method of removing measurement artifacts (the four-cycle component in the NIR bands of the Terra prelaunch polarization measurements). In Figs. 1 to 5, the fitted expected values are shown as a solid line. There are several issues that are disturbing:

- **There is no dominant two cycle pattern in bands 10-15, only bands 8, 9 and 16 show a clear two cycle pattern.** This suggests that measurement artifacts dominate the signal in bands 10-15.

- **For bands 8,9, and 16, a rotation of the polarizer by $180°$ changes the measured value, although the effect should be zero.** The average difference is between 2.0 and 2.5% for a viewing angle of 45°, which is a significant portion of the total effect (difference between maximum and minimum is 13.5% for band 8, 8% for band 9 and 7.5% for band 16).

- **The position of the maxima for bands 8 and 9 is at about $\pm 180°$, but for band 16 it is at about $\pm 90°$.** Since MODIS is a complicated system, this may not be impossible, but for a simple mirror this would be impossible. For a theoretical air-dielectric interface with a refractive index greater than 1, the reflected component is either unpolarized or horizontally polarized (depending on the incidence angle), but never vertically polarized. This suggests that either there is a problem with the prelaunch polarization measurements, or that the mirror is not the primary source of polarization for either band 16 or bands 8 and 9, or that the polarization characteristics of the MODIS mirror are very different from those of a simple air-dielectric interface.

- **There is a four cycle pattern in bands 13-15, but not in band 16.** The four-cycle pattern has been described for the Terra prelaunch polarization measurements in [4] as being caused by multiple passes of the light between the polarization filter and the NIR MODIS focal plane filters. There is no explanation in the paper why band 16 does not have the four-cycle pattern.

- [4] suggest to retrieve the 'true' polarization pattern with Fourier analysis, keeping only those components corresponding to the $\cos 2\alpha$ and $\sin 2\alpha$ terms. Although this approach works well with the data presented in their paper (for Terra band 15), **no significant Fourier component could be retrieved from bands 13 and 15 for Aqua.**

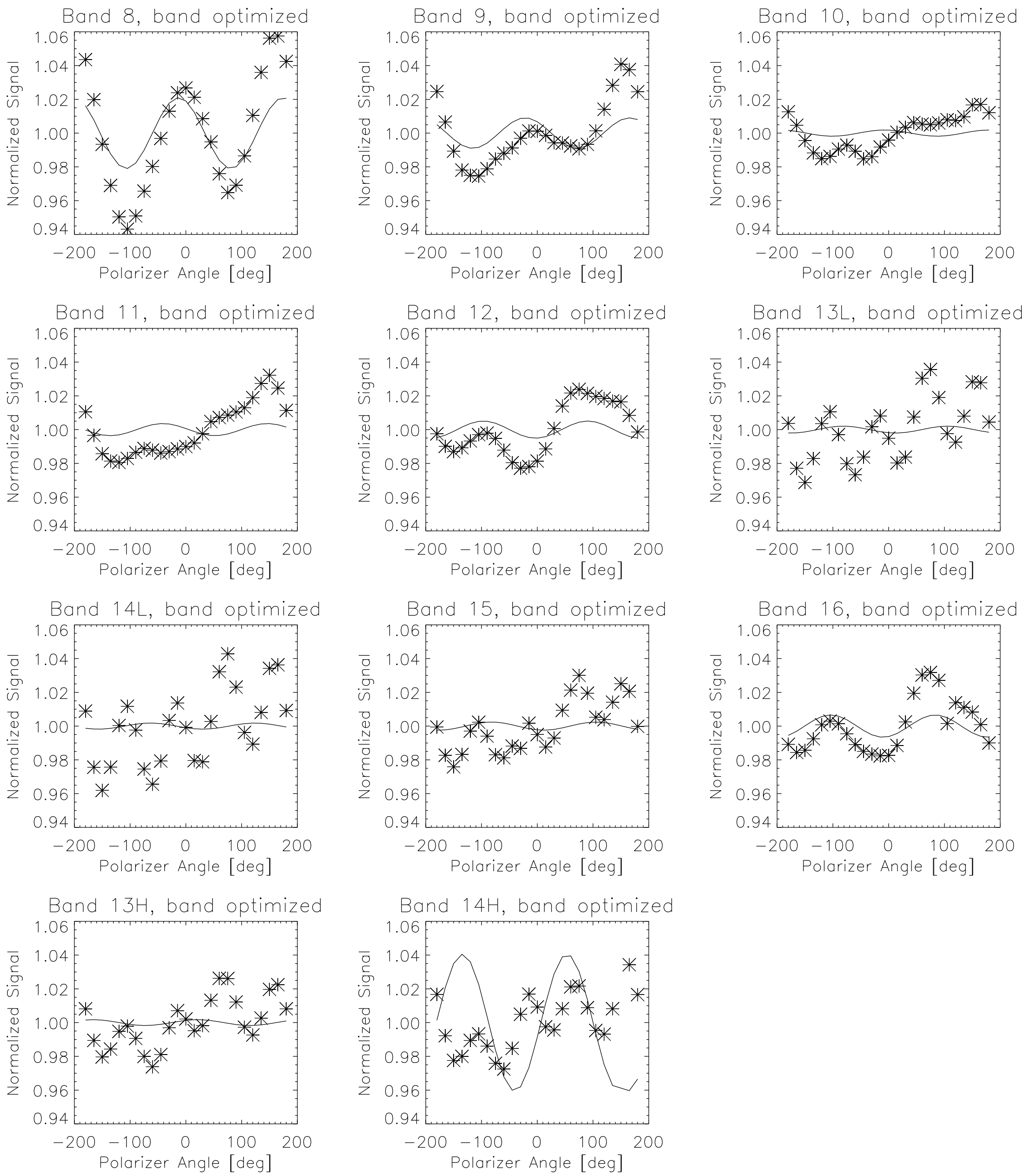

Figure 1: Polarization at a viewing angle of $-45°$, corresponding to an incidence angle on the scan mirror of $15.5°$. The stars show the band optimized prelaunch measurements, the solid line shows the two-cycle component.

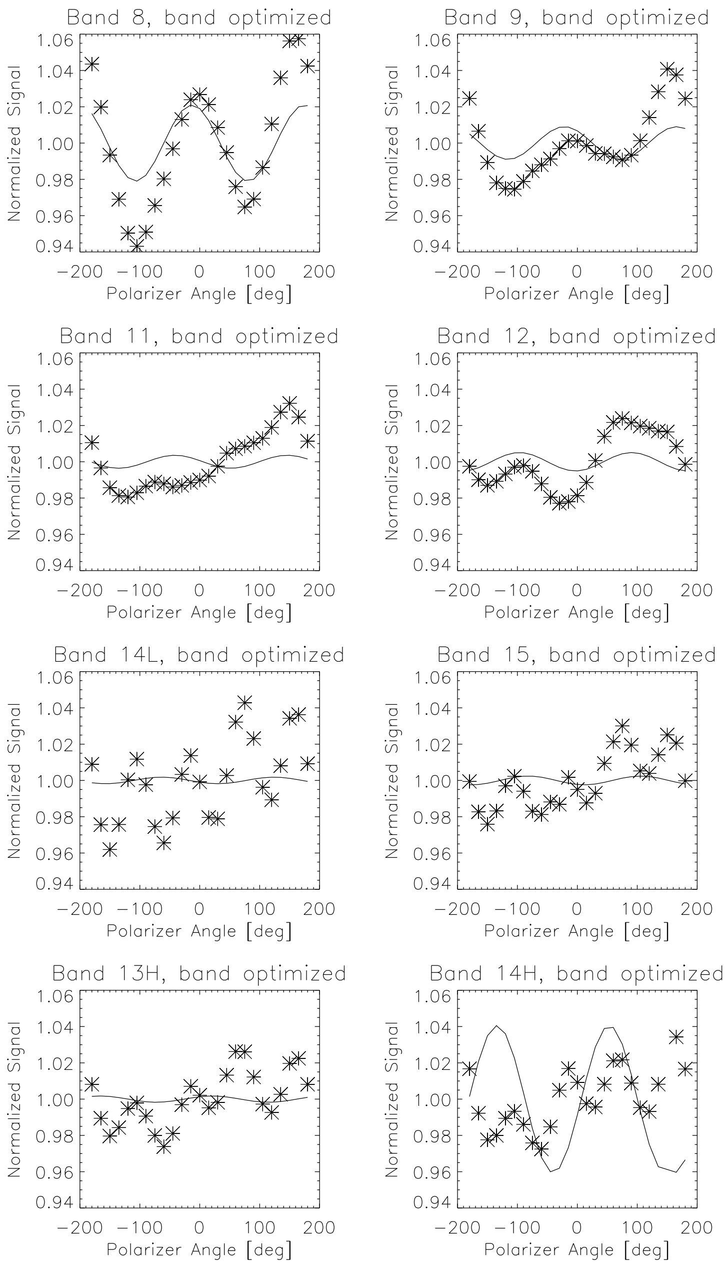

Figure 2: Polarization at a viewing angle of $-22.5°$, corresponding to an incidence angle on the scan mirror of $26.75°$. The stars show the band optimized prelaunch measurements, the solid line shows the two-cycle component.

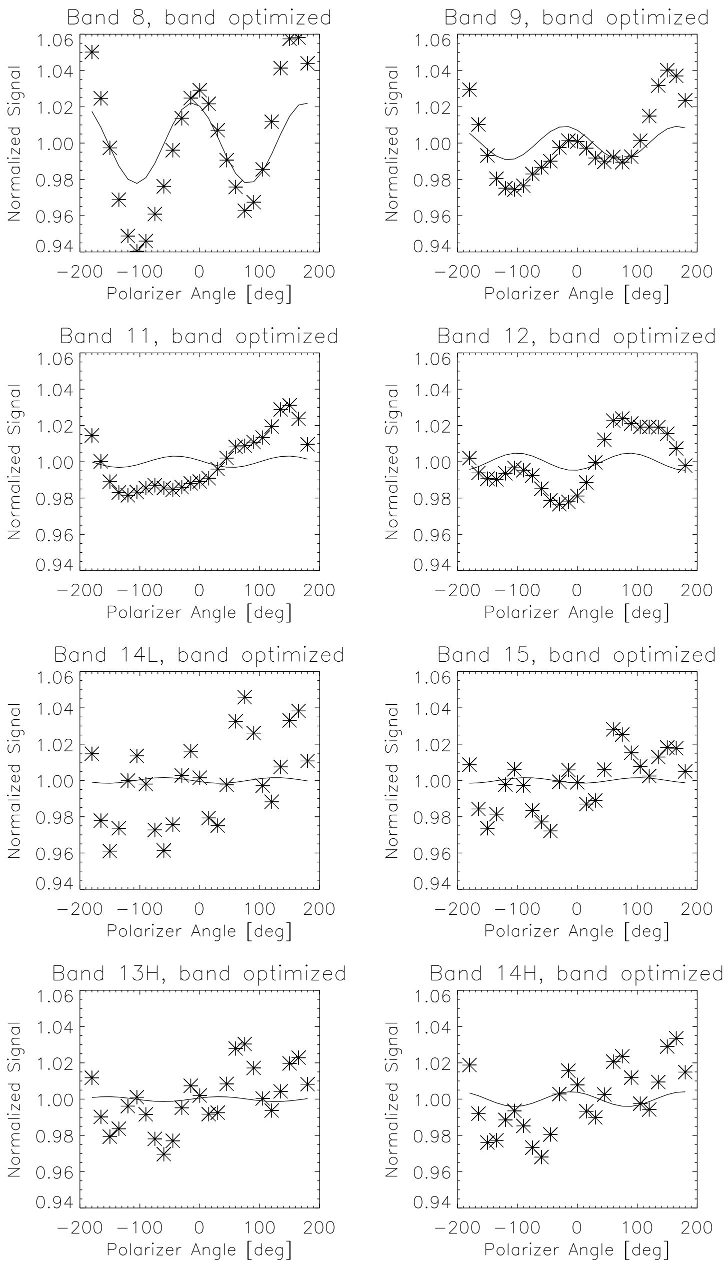

Figure 3: Polarization at a viewing angle of 0°, corresponding to an incidence angle on the scan mirror of 38°. The stars show the band optimized prelaunch measurements, the solid line shows the two-cycle component.

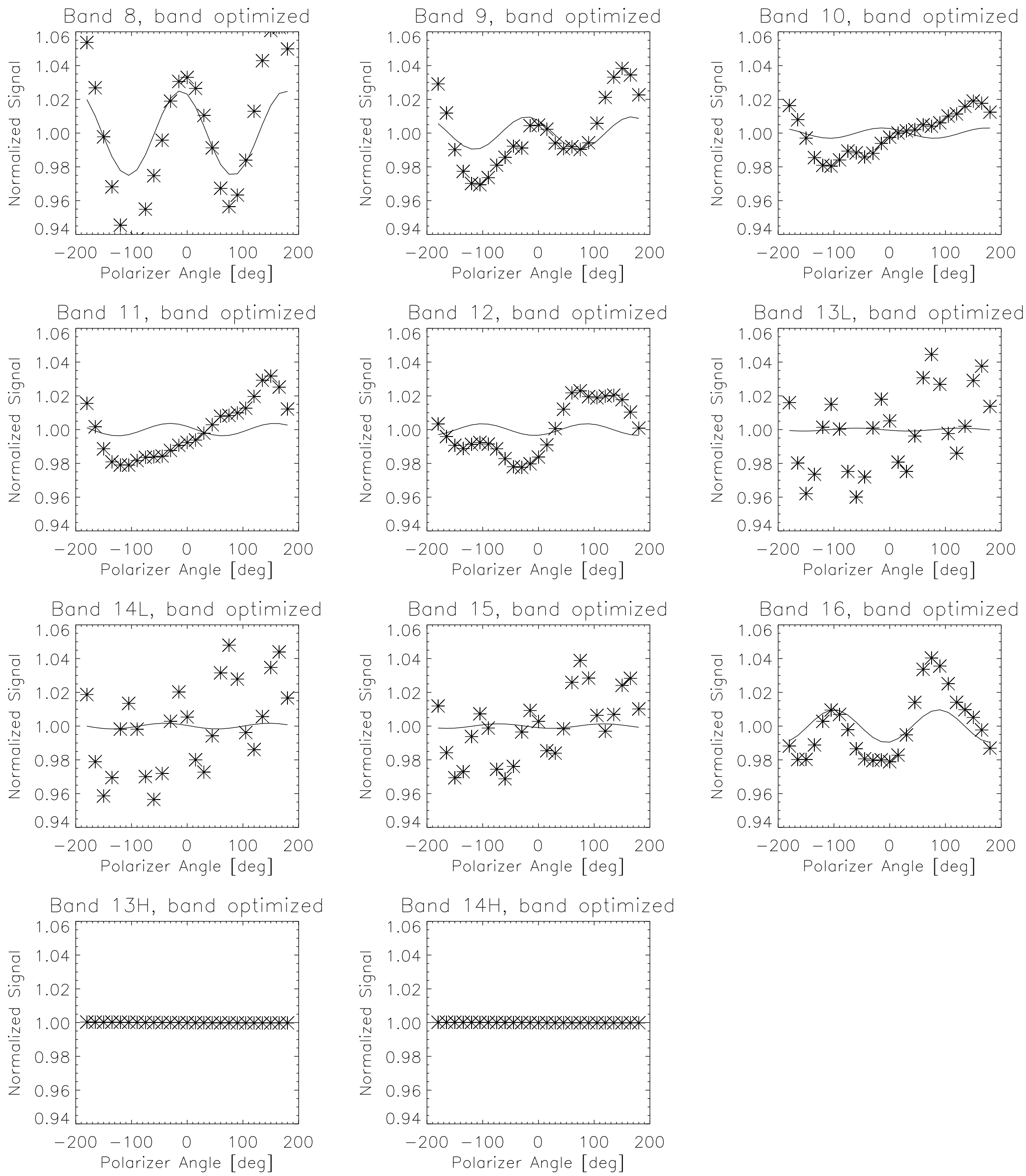

Figure 4: Polarization at a viewing angle of $+22.5°$, corresponding to an incidence angle on the scan mirror of $49.25°$. The stars show the band optimized prelaunch measurements, the solid line shows the two-cycle component.

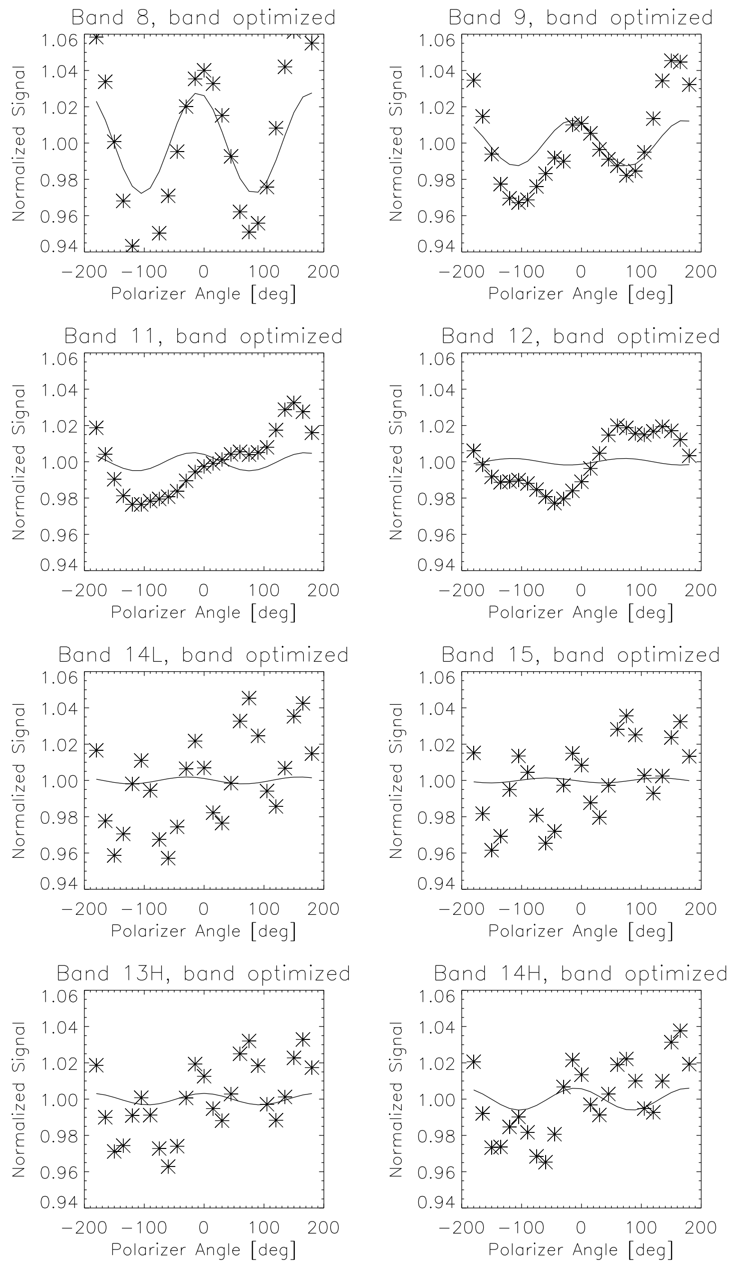

Figure 5: Polarization at a viewing angle of $+45°$, corresponding to an incidence angle on the scan mirror of $60.5°$. The stars show the band optimized prelaunch measurements, the solid line shows the two-cycle component.

5 Derivation of the polarization correction

An algorithm to derive the polarization correction for ocean color has been described by [2]. The goal is to derive the Mueller matrix components m12 and m13, which are applied to the Stokes vector components. This section shows how m12 and m13 derived by the ocean color group in Miami (RSMAS) can be related to the prelaunch measurements.

The crucial step is to derive the Stokes vector for each rotation angle of the polarizer. If this is achieved, the application of the Mueller matrix is straightforward. The problem is, that as of the writing of this report, the uncertainties regarding the definition of the angles are unresolved. This leaves four obvious choices for the angle definition, affecting the calculation of the Stokes vector:

1. Assume $0°$ for the rotation angle of the polarizer corresponds to **horizontally** polarized light as seen from MODIS.
2. Assume $0°$ for the rotation angle of the polarizer corresponds to **vertically** polarized light as seen from MODIS.
3. Assume increasing rotation angles are **counterclockwise** as seen from MODIS.
4. Assume increasing rotation angles are **clockwise** as seen from MODIS.

Assumptions 3 and 4 cover all possibilities. Assumptions 1 and 2 do not cover all possibilities (e.g. horizontally polarized light could be achieved at a rotation angle of the polarizer of $45°$), but assumptions 1 and 2 are the most likely choices. Choosing either assumption 1 or 2 and either assumption 3 or 4 yields a total of four combinations.

The Stokes vectors were calculated from [1] at the following angles: $[-180°, -135°, -90°, -45°, 0°, 45°, 90°, 135°, 180°]$ with the following choices: a clockwise (as seen from MODIS) rotation of the polarizer increases the angles, and $0°$ for the rotation angle of the polarizer corresponds to horizontally polarized light. Different assumptions would shift the position of the maxima and minima, but would not change the magnitude of the oscillation. The results are shown in Fig. 6, the stars show the polarization correction calculated with the Miami polarization matrix, the dashed line shows the two cycle component of eq. 1 derived by Fourier transformation. The agreement between the stars and the dashed line is very good, except for band 14. The solid line shows the measurements, which clearly do not agree well with the stars. For the other four viewing angles at which prelaunch polarization measurements were made, the agreement is similar (not shown here). **This suggests that Miami used the two cycle component to calculate the polarization correction, using the same assumptions as described in this paragraph.** It is not known to us how Miami arrived at these assumptions. It is also not known why band 14 doesn't agree. Recently, Jim Brown from RSMAS has provided his software, which will hopefully resolve these issues, and may also give indications which choice of assumptions is correct.

Although Fig. 6 provides good qualitative agreement, a closer look at all detectors for band 16 (Fig. 7) shows that there is about 0.5% difference between the Miami correction and the two cycle component, and the phase of the difference varies with wavelength (for detector 1, the maximum of the correction is to the right of the maximum of the two cycle component, for detector 10 it is to the left). In [3], it is mentioned that the incidence angles varies by detector from $-0.4°$ to $+0.4°$, this effect has not yet been considered in the analysis of this report. Hopefully the software provided by Jim Brown will resolve this issue (his software is based on MCST software).

6 Outlook

Based on the results of this analysis, a new polarization correction could be derived along the following lines:

- instead of using a Fourier transformation to extract the two cycle component we could derive the coefficients of eq. 1 with a least squares fit, which would likely result in a better approximation of the measurements
- we might use the band optimized measurements instead of the individual detectors
- if the angle definition remains unclear, we could derive four datasets (one for each combination of assumptions) and find out which makes most sense when applying it to MODIS L2 products and comparing it to SeaWiFS data

Furthermore, we should try to make sure that for NPP/VIIRS the issues listed in section 4 are resolved, since we suspect that the same equipment and setup will be used by SBRS for VIIRS as for MODIS.

The software provided by Jim Brown will hopefully resolve the remaining uncertainties about the method the Mueller Matrix was calculated by RSMAS.

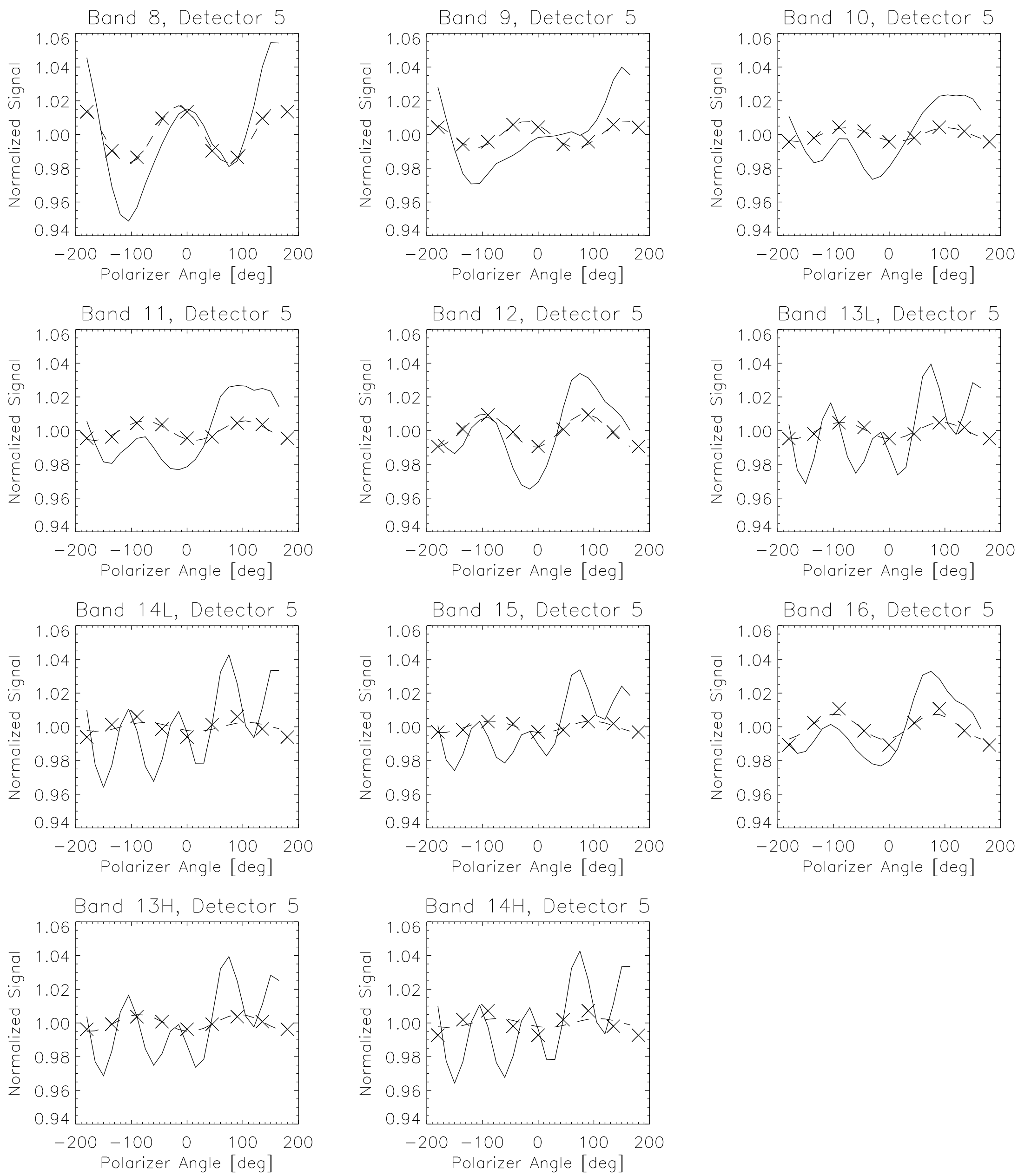

Figure 6: Prelaunch polarization measurements for detector 5 (product order), at a viewing angle of $-45°$. The solid line shows the measurements, the dashed line shows the two cycle component extracted by Fourier analysis from the measurements. The crosses show the MODIS polarization correction calculated from the Miami Mueller matrix.

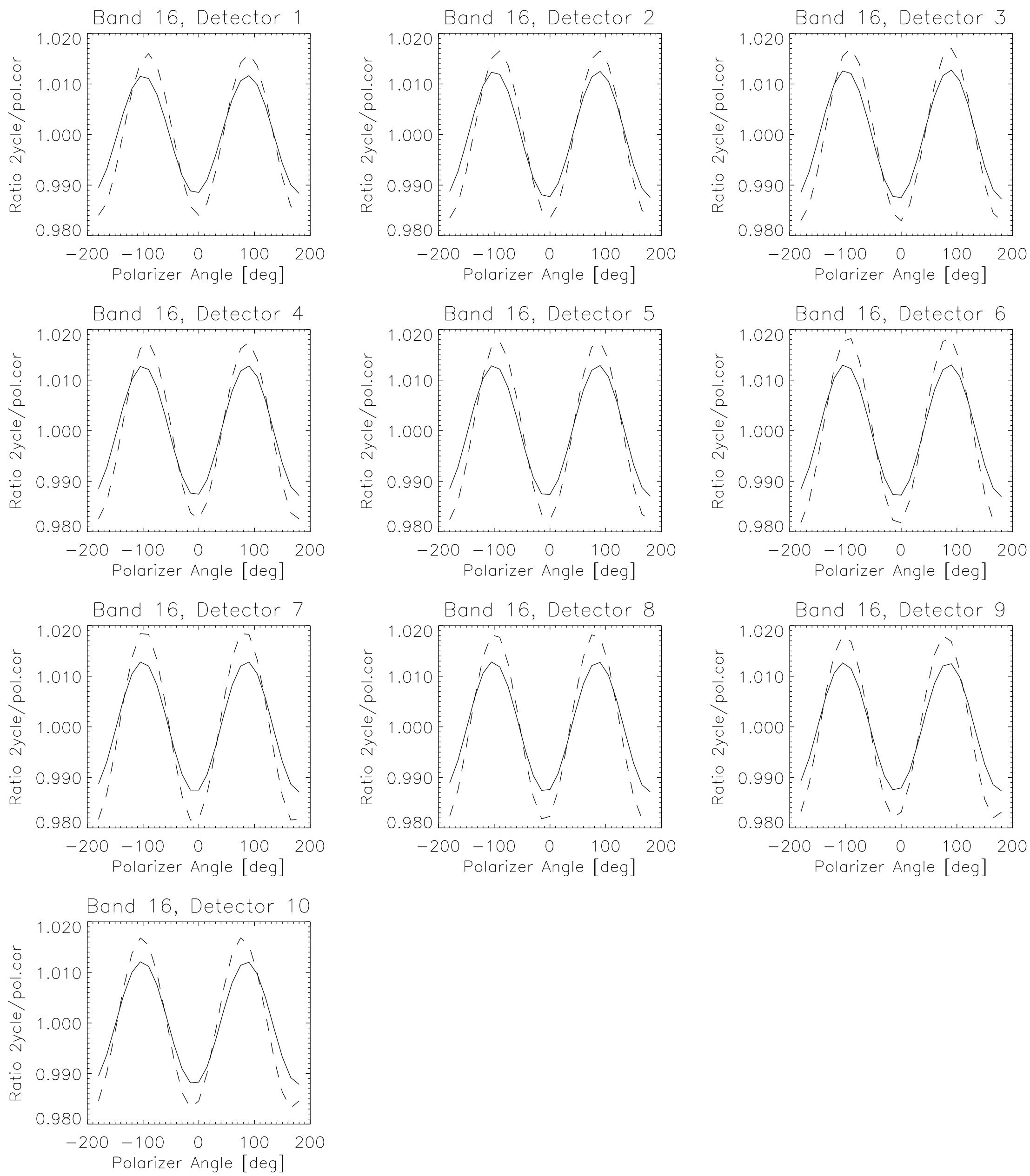

Figure 7: The two cycle component of band 16, viewing angle of +45° is shown as a solid line for all 10 detectors (product order), the dashed line shows the Miami polarization correction. Stokes vector calculation and Mueller matrix application were done at all angles where measurements were taken by SBRS.

7 Appendix: Polarization Measurements for Individual Detectors

The appendix contains plots of the Aqua MODIS prelaunch polarization measurements for each detector (in SBRS order) for a viewing angle of $-45°$, corresponding to an incidence angle on the scan mirror of $15.5°$. The solid, dashed, and dotted line show the measurements for different settings of Aqua MODIS (different UAID numbers). A constant line means that the algorithm described in section 3 did not retrieve meaningful values, which is typically due to the band being saturated. The solid line generally gives the best data and was used for the analysis in this report, except for band 9 at a viewing angle of $+22.5°$. The UAID numbers of the data sets used in this report for viewing angles from $-45°$ to $+45°$ are 2101, 2103, 2105, 2107, 2110, resp. (with 2109 for band 9 (odd subindices, 1, 3, ..., 49) for a viewing angle of $+22.5°$).

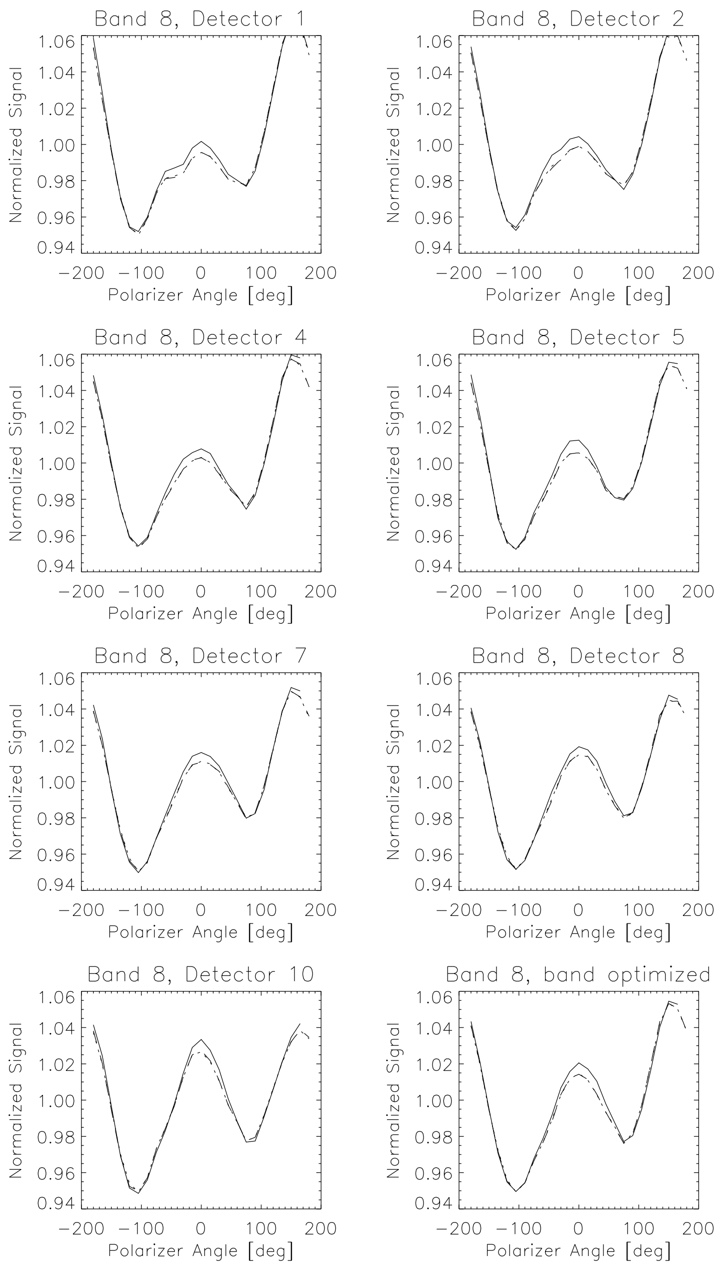

Figure 8: Prelaunch polarization measurements of Aqua MODIS band 8 at a viewing angle of $-45°$. See page 14 for explanations.

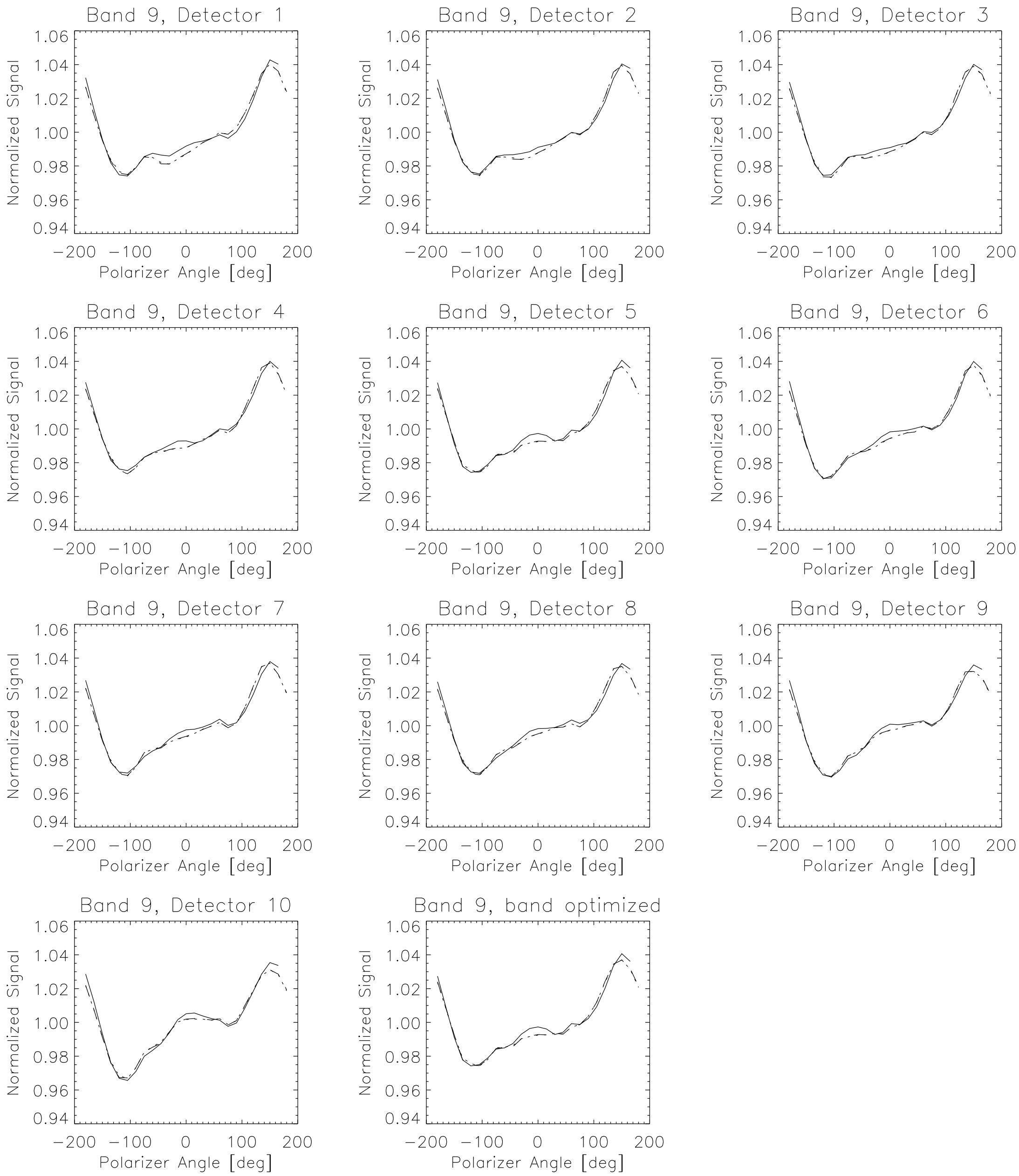

Figure 9: Prelaunch polarization measurements of Aqua MODIS band 9 at a viewing angle of $-45°$. See page 14 for explanations.

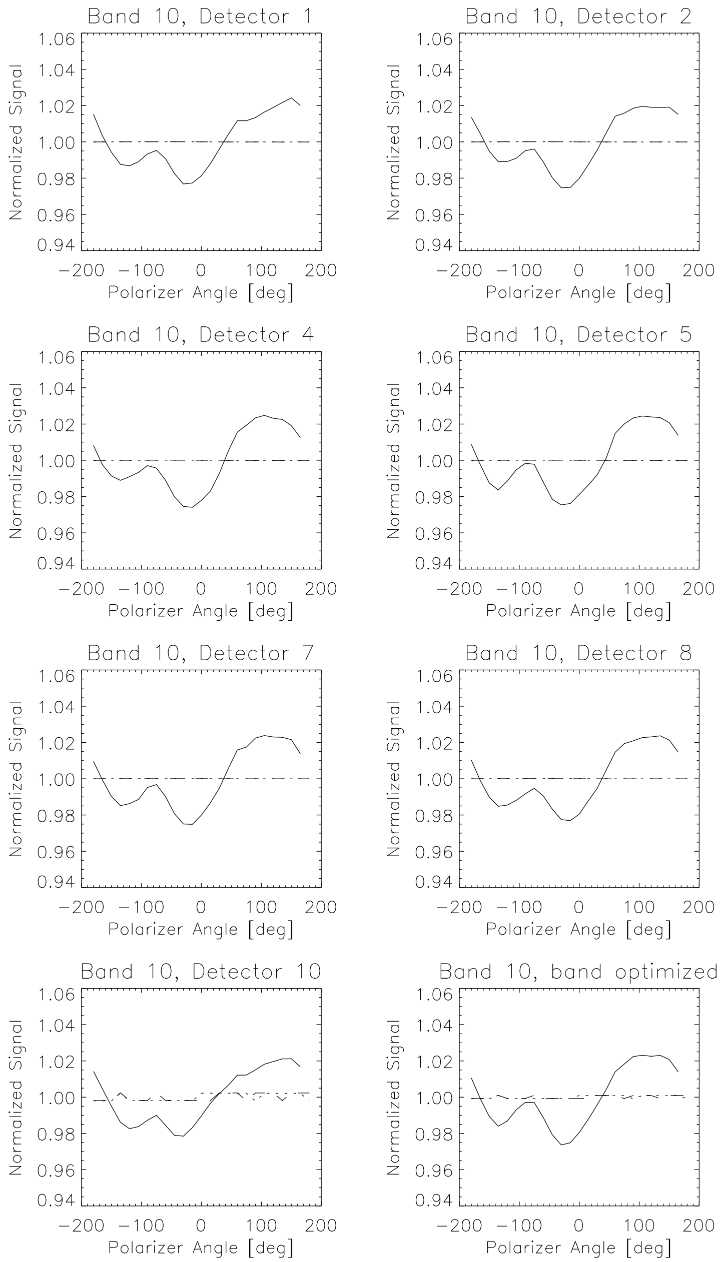

Figure 10: Prelaunch polarization measurements of Aqua MODIS band 10 at a viewing angle of $-45°$. See page 14 for explanations.

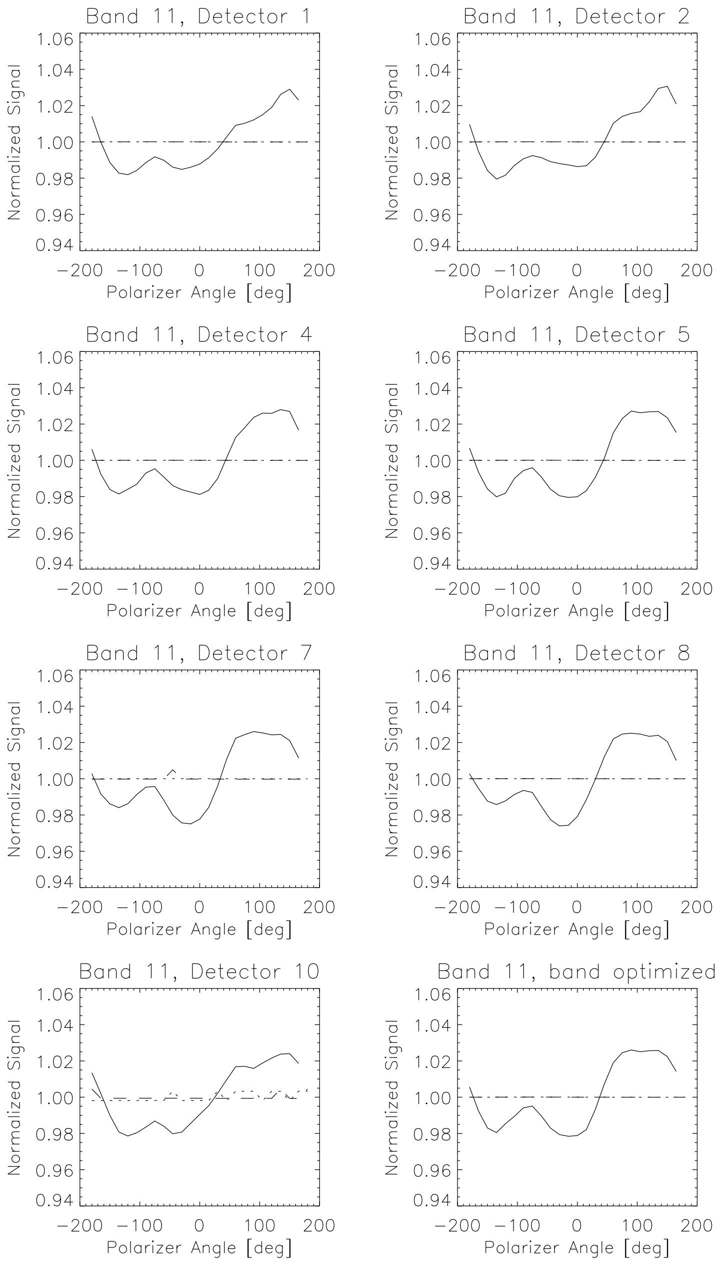

Figure 11: Prelaunch polarization measurements of Aqua MODIS band 11 at a viewing angle of $-45°$. See page 14 for explanations.

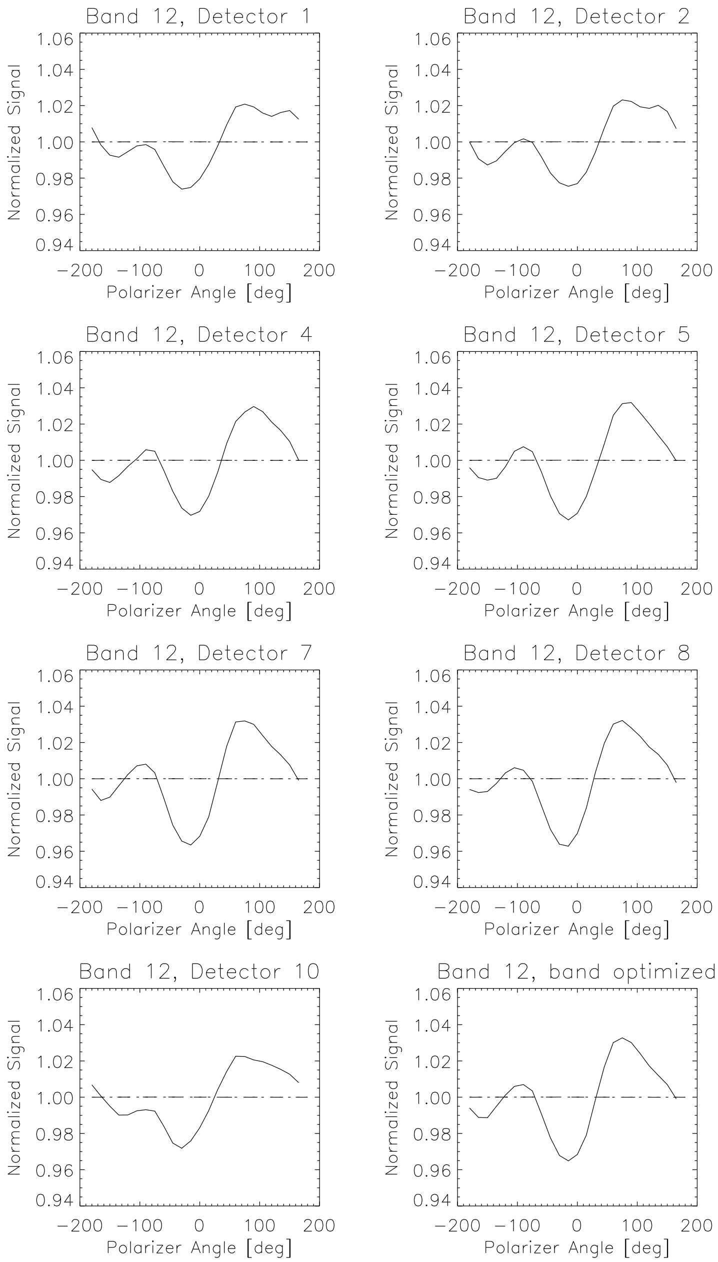

Figure 12: Prelaunch polarization measurements of Aqua MODIS band 12 at a viewing angle of $-45°$. See page 14 for explanations.

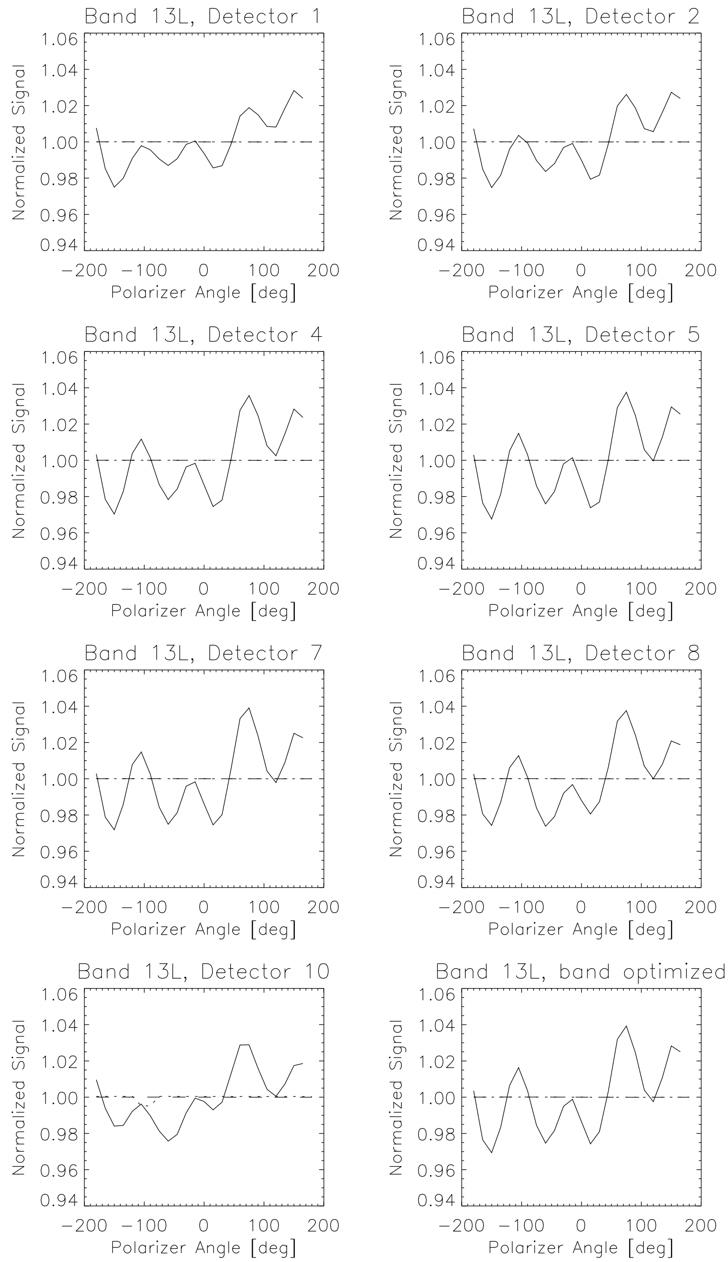

Figure 13: Prelaunch polarization measurements of Aqua MODIS band 13L at a viewing angle of −45°. See page 14 for explanations.

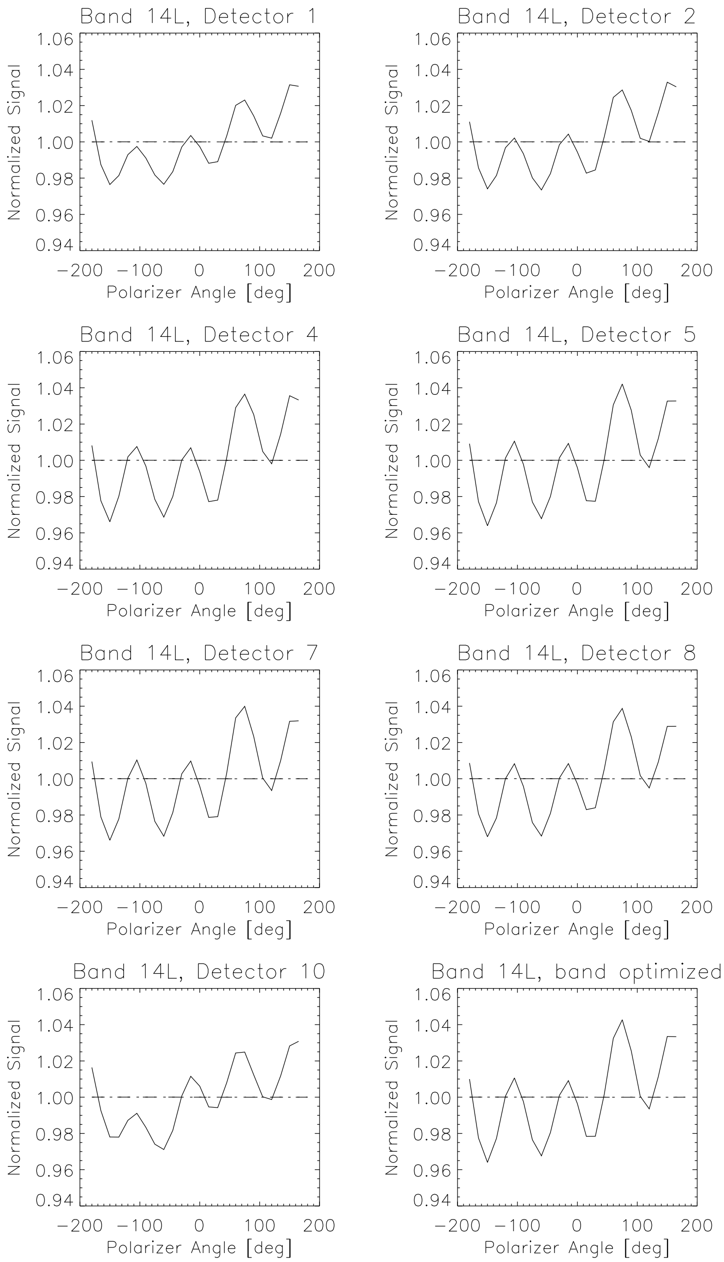

Figure 14: Prelaunch polarization measurements of Aqua MODIS band 14L at a viewing angle of $-45°$. See page 14 for explanations.

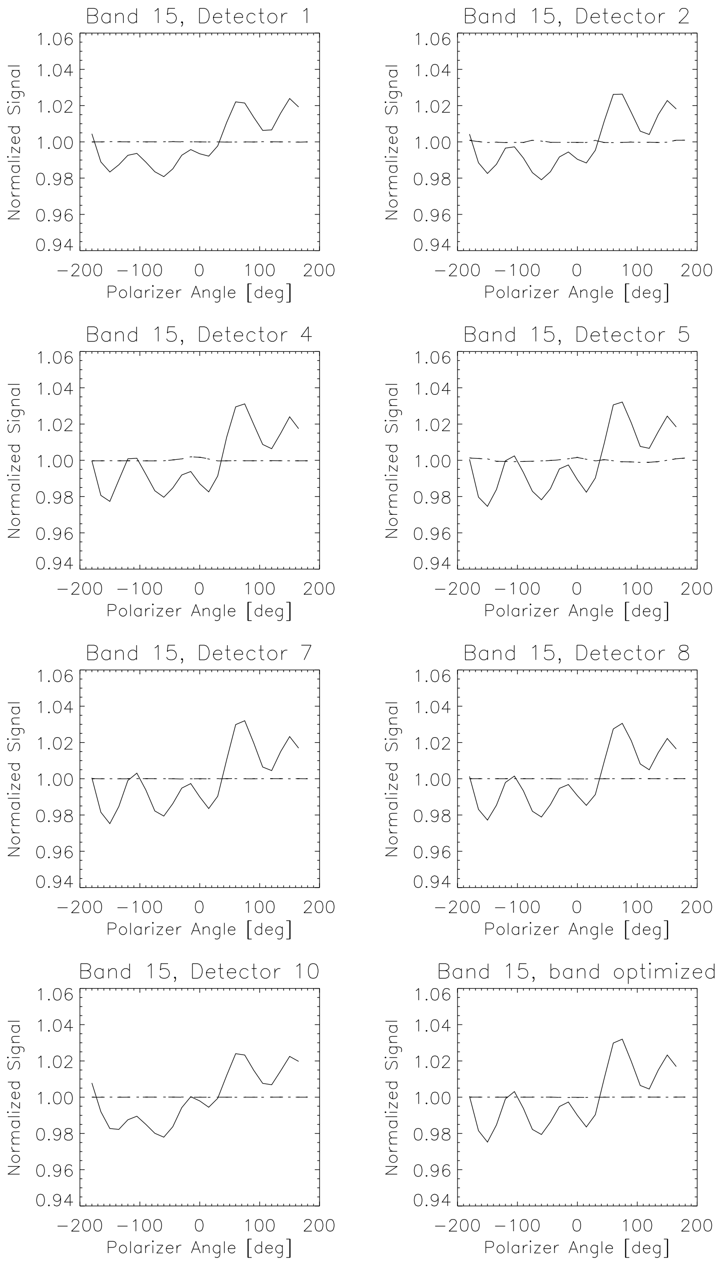

Figure 15: Prelaunch polarization measurements of Aqua MODIS band 15 at a viewing angle of $-45°$. See page 14 for explanations.

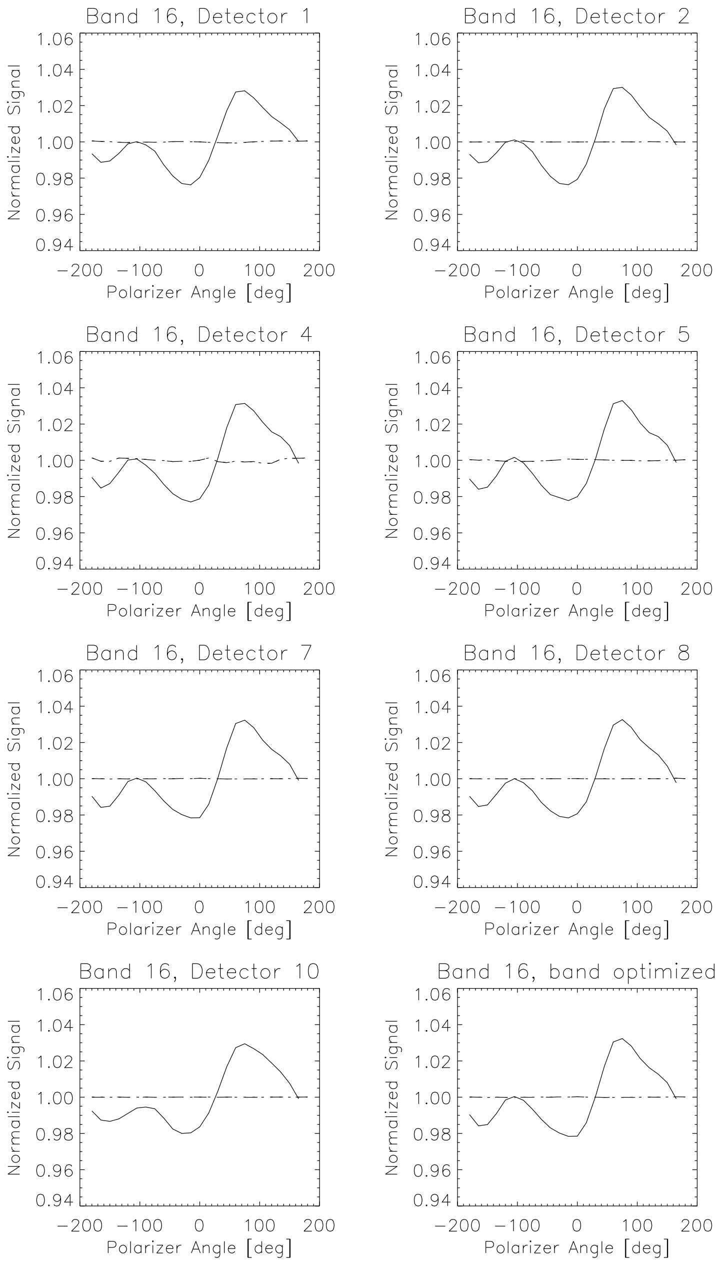

Figure 16: Prelaunch polarization measurements of Aqua MODIS band 16 at a viewing angle of $-45°$. See page 14 for explanations.

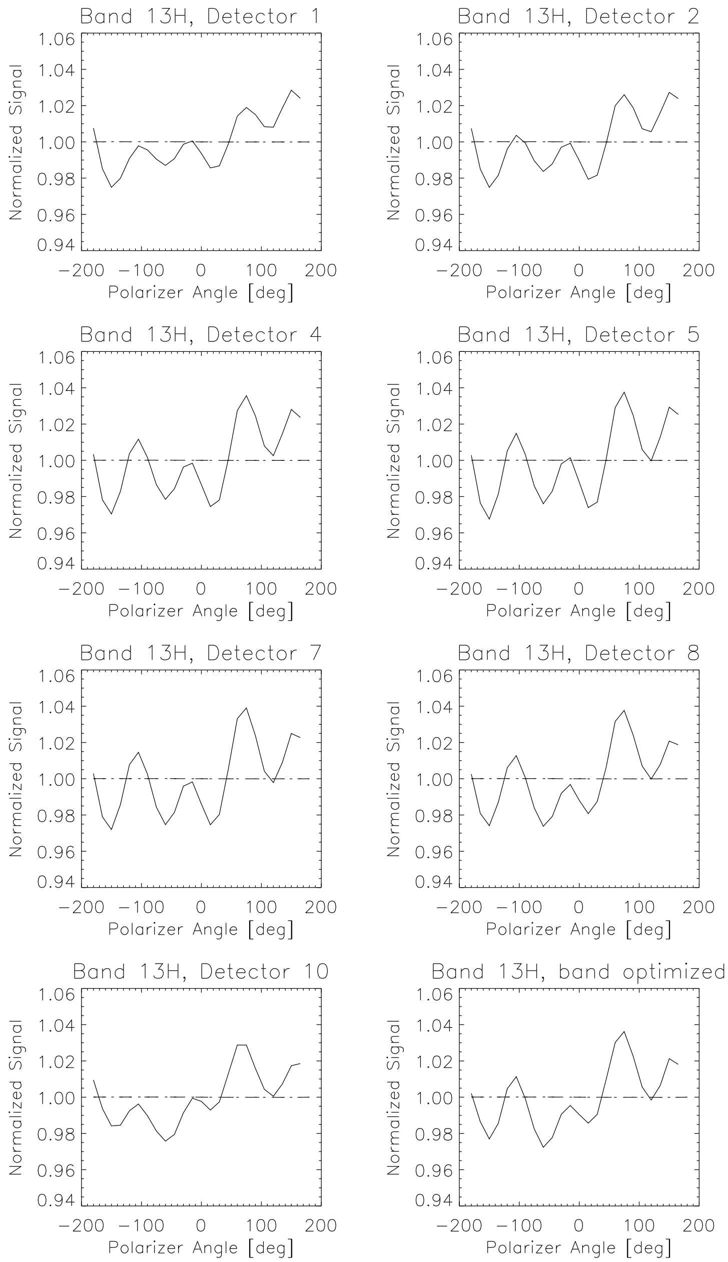

Figure 17: Prelaunch polarization measurements of Aqua MODIS band 13H at a viewing angle of $-45°$. See page 14 for explanations.

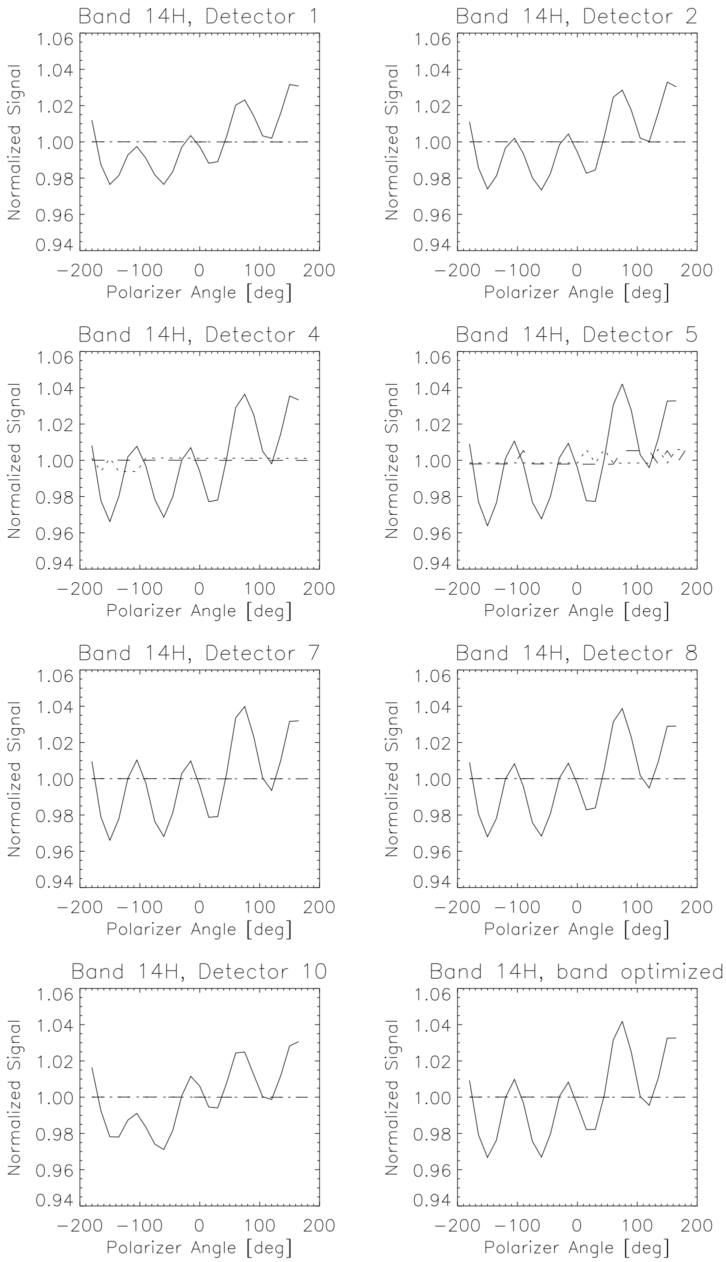

Figure 18: Prelaunch polarization measurements of Aqua MODIS band 14H at a viewing angle of $-45°$. See page 14 for explanations.

References

[1] Collet, E., Polarized Light, Marcel Dekker, Inc., New York, ISBN 0-8247-8729-3

[2] Gordon, H.R., Tao Du, Tianmin Zhang, *Applied Optics*, 1997, Vol. 36, No. 27, 6938-6948.

[3] Xiong S., Sun J., Xiong J., MODIS FM1 Pre-Launch Polarization Test Data Processing and Analysis, MCST Internal Memorandum, October 2002

[4] Young, J., Knight, E., Merrow, C., SPIE Conference on Earth Observing Systems III, San Diego ,California, July 1998, SPIE Vol. 3439, 247-256